The Future of SAFER Science and Integration of DDESB's Risk-Based Explosives Siting Tool with ESS

Presenter: Robert T. Conway, Naval Facilities Engineering Service Center, CI62, 1100 23rd Avenue, Bldg 1100, Port Hueneme, CA 93043-4370, Phone: 805-982-1248; FAX: 805-982-3481; E-mail: Robert.Conway1@navy.mil

Co-Author: John W. Tatom, APT Research, Inc, 4950 Research Drive, Huntsville, AL 35805. Phone: 256-327-3392; FAX: 256-837-7786; E-mail: JTatom@APT-Research.com

Co-Author: Lea Ann Cotton, DoD Explosives Safety Board, 2461 Eisenhower Avenue, Room 856C, Alexandria, VA, 22331. Phone: 703-325-1369; FAX: 703-325-6227; E-mail: Lea.Cotton@DDESB.osd.mil

Co-Author: Phillip C. Wager, Naval Facilities Engineering Service Center, CI62, 1100 23rd Avenue, Bldg 1100, Port Hueneme, CA 93043-4370, Phone: 805-982-1239; FAX: 805-982-3481; E-mail: Phillip.Wager@navy.mil

CV (Robert Conway)

Robert Conway obtained both his Bachelor's and Master's of Science in Structural Engineering at the University of California, San Diego. His graduate work consisted of analyzing the vulnerability of conventional infrastructure to blast effects, culminating in his thesis work focusing on the blast response of bridge decks. Robert works for the Naval Facilities Engineering Service Center in a variety of areas within explosive safety. His work primarily includes quantifying blast effects on structures, secondary debris effects, and blast wave mitigation.

ABSTRACT

The US Department of Defense Explosives Safety Board (DDESB) sponsors the DDESB Science Panel whose charter includes developing and improving the explosion effects and consequence algorithms detailed in DDESB Technical Paper 14 and embedded within the DDESB's risk-based explosives siting tool, the Safety Assessment For Explosives Risk (SAFER) software. Consequently, the Science Panel has begun planning for improvements of the current SAFER Version 3.1 software. Several potential changes identified by the Science Panel are described, to include:

- Addition of new and possibly scalable Potential Explosion Site (PES) and Exposed Site (ES) models
- Consideration of PES/ES orientation
- Consideration of PES clover-leaf debris pattern
- Transition to a component-based building damage methodology

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- Primary fragment and debris generation model refinements
- Consideration of blast wave and fragment sequencing
- Refinements of the thermal model
- Updates to various parameters as a result of test data analysis

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1.0 INTRODUCTION

The US Department of Defense Explosives Safety Board (DDESB) sponsors the DDESB Science Panel whose charter includes developing and improving the explosion effects and consequence algorithms detailed in DDESB Technical Paper (TP) 14[1] and embedded within the DDESB's risk-based explosives siting tool, the Safety Assessment For Explosives Risk (SAFER)[2] software. TP 14 and SAFER have gone through multiple revisions over the years, with the constant goal being to enhance the capabilities of the software, expand the range of validity, and improve the consequence models as the state-of-the-art of the science advances. Consequently, the Science Panel has begun planning for improvements of the current SAFER Version 3.1 software, and the details of this advancement are discussed herein.

The DDESB also manages the DoD's Explosives Safety Siting (ESS) software. The DDESB's risk-based explosives siting tool will be incorporated as a module of the ESS software tool by October 2013. The Naval Facilities Engineering Service Center (NAVFAC ESC) is the design authority for ESS, and has begun planning for this integration. The scope and status of this planning effort are discussed.

2.0 BACKGROUND

The Risk Based Explosives Safety Criteria Team (RBESCT) was formed in 1997 as an initiative to develop and implement risk-based explosives siting within the DoD[3]. In December 1999, the RBESCT recommended and the DDESB approved the use of a quantitative risk assessment (QRA) model and risk acceptance criteria for a 3-year trial period. This risk-based methodology was released in the form of SAFER Version 1 in May 2000. In May 2002, the DDESB approved and released SAFER 2.0 and extended the trial period for the use of the QRA model and risk acceptance criteria to December 2004. In February 2007, the DDESB approved the use of SAFER 3.0, and in May 2007 the DDESB approved language for incorporation of risk-based explosives siting into DoD 6055.09-STD[4] which concluded the trial period and institutionalized risk-based explosives siting methodology and acceptance criteria within the DoD. SAFER 3.1 is the current version of the software, and was released in 2009 after approval by the DDESB.

The Science Panel has recently begun the process of performing a study to revisit all algorithms currently in TP 14. The purpose of the initial study was simply to identify algorithms, methods, and equations that the Panel felt needed to be updated, and to identify the version of TP 14 and SAFER that would implement the update. The rationale behind any suggested change in TP 14 was generally for one of three reasons:

- The state-of-the-art for a particular consequence algorithm has improved since the initial implementation
- The use of SAFER has expanded beyond the original range of applicability for a given consequence algorithm

- Incorporation of geospatial relationship data (through integration with ESS) would facilitate improvement or fidelity of some algorithms without requiring additional user input

The Science Panel is taking both a short-term and long-term approach for changes within TP 14. Changes will be identified for implementation into the next version of SAFER assumed to be a stand-alone software tool similar to its current construct (SAFER 3.X), and changes will be identified for implementation into the DDESB's risk-based explosives siting tool when it is eventually integrated with ESS.

3.0 SAFER SCIENCE UPDATE

As with all scientific models, it is imperative to keep abreast of the state-of-the-art in that discipline and update accordingly. Additionally, the user requirements must be clearly identified and the realm of applicability clearly stated. Since the inception of the first version of SAFER, the scientific state-of-the-art, the user requirements, and the realm of applicability have changed. Science is constantly improving prediction algorithms for the complex events associated with explosives scenarios, gradually improving accuracy and asymptotically approaching the best point estimate of the "answer." User requirements and the range of desired use, on the other hand, are dynamic by nature and continually evolve over time. It is the responsibility of the RBESCT and Science Panel to update both TP 14 and the DDESB's risk-based explosives siting tool to satisfy this evolutionary process.

In addition to the aforementioned causes for change, it is just as critical to understand the constraints for future changes to both the scientific algorithms and the software. The Science Panel has participated in the ongoing development of algorithms defining azimuth-dependant debris density functions, as well as three-dimensional break-up and debris throw models. The current constraints of the SAFER software do not allow for full consideration of these factors, and incorporation of geospatial data into the software has been desired for some time. It is the goal of the DDESB to incorporate its risk-based explosives siting tool as a module of the ESS software tool by October 2013. This will utilize the spatial relationships and some facility information already stored in the ESS database. In assessing all potential changes to the TP 14 algorithms, each change was identified as either being appropriate for the next stand-alone version of SAFER (referred to as SAFER 3.X hereafter), or if it would be more appropriate to incorporate after the risk-based explosives siting tool has been integrated with ESS.

Finally, the "big picture" needs to be considered when updating TP 14. At least two philosophical dilemmas need to be considered prior to making changes. One such dilemma is the ultimate purpose of this tool: is it only to be an explosives safety siting tool, providing an alternative to Quantity-Distance (QD), or is it to also be a state-of-the-art engineering analysis tool? In its current form, risk-based siting provides an alternative to QD siting, but demands much more knowledge and data input from the user. Despite this additional information required, SAFER still makes simplified assumptions to keep the amount of required input and knowledge base of the user at a reasonable level.

Additionally, some of these simplified models keep the QRA tool fast-running, and provide the user with an immediate answer. In order to achieve higher fidelity in the answer in many cases, much more extensive input would be required. Developing the tool such that it required extensive, detailed user input would deter many users from utilizing risk-based siting, and would limit the use of the tool to a minimal amount of specialized personnel.

It is the desire of the Science Panel to update TP 14 in such a way that all parties can utilize the QRA tool. The Panel has begun identifying the path ahead to both improve the existing simplified models, as well as develop new models that require more extensive input to achieve an answer with greater fidelity. This provides the user the option of increasing the accuracy of the answer by providing more detail, or using the default assumptions that require the current level of effort to develop a risk assessment. Eventually, additional DDESB approved engineering assessments models such as TP 13[5] and TP 16[6] can be incorporated, presenting a hybrid between QD siting, risk-based siting, and engineering analysis.

Another dilemma regarding the direction of the TP 14 update is the ultimate goal of risk-based analysis. Namely, does it have to simply do a better job of risk management than QD siting, or does it need to be a state of the art engineering analysis that provides a hazard assessment more specific to the situation being analyzed? In QD, minimal consideration is given for the Potential Explosion Site (PES) structure type or orientation in defining acceptable standoff distances, and even less is given for the Exposed Site (ES). Risk-based siting already provides a greater amount of fidelity in its answer than QD, but the question that must be asked is, "How good is good enough?"

A final hurdle that must be addressed with an advanced physics based model is the possible irregularities that arise when multiple variables are introduced. QD siting is based on curves that in many cases require increased distance as the NEW is increased. With a physics-based model it's possible to increase NEW or decrease the distance with all other variables held constant, and get an answer that shows less risk. This would be the exception rather than the rule, but one example is a physics-based debris model that has an aggressive dynamic mass distribution (i.e. as the NEW is increased the debris becomes more and more pulverized). If a robust ES structure was at such a distance that the biggest hazard was debris, one could imagine it possible that increasing the NEW could decrease the debris hazard and slightly decrease the overall risk. Of course, the overpressure would eventually become the driver in the risk answer and the overall risk would continue to rise as a function of increasing NEW. This scenario, though physically real, is quite rare, but is inherently counter-intuitive to the QD and risk-based siting processes. Nonetheless, this type of issue needs to be addressed, both from a scientific and a philosophical perspective.

The aforementioned issues are all being considered as the Science Panel moves forward in improving the current algorithms in TP 14. This paper addresses those scenarios where immediate need for improvement has been identified and a path forward defined. The update is laid out in a sequential process corresponding to the six "Groups" and 26 "Steps" of TP 14. The architecture of the QRA method is shown in Table 1 and Figure 1. Note that the Group 6 Steps are not addressed in this paper.

Table 1. The Six Groups and 26 Steps of the TP 14 QRA Model

Group 1	Steps 1-4	<u>Situation Definition, Event and Exposure Analyses</u> Includes user inputs that describe the situation (PES and ES) and calculates probability of event, exposure, and yield
Group 2	Steps 5-8	<u>Pressure and Impulse Branch</u> Calculates the magnitude of the fatality mechanisms of pressure and impulse
Group 3	Steps 9-10	<u>Structural Response Branch</u> Calculates the magnitude of the fatality mechanisms of building collapse and broken windows (overall building damage)
Group 4	Steps 11-18	<u>Debris Branch</u> Calculates the magnitude of the fatality mechanisms for multiple types of flying debris
Group 5	Steps 19-22	<u>Thermal Branch</u> Calculates the magnitude of the fatality mechanism of thermal effects for HD 1.3 scenarios only
Group 6	Steps 23-26	<u>Aggregation Summation</u> Aggregates the total magnitude and risks of all fatality mechanisms, calculates the desired measures of risk, and assesses overall uncertainty

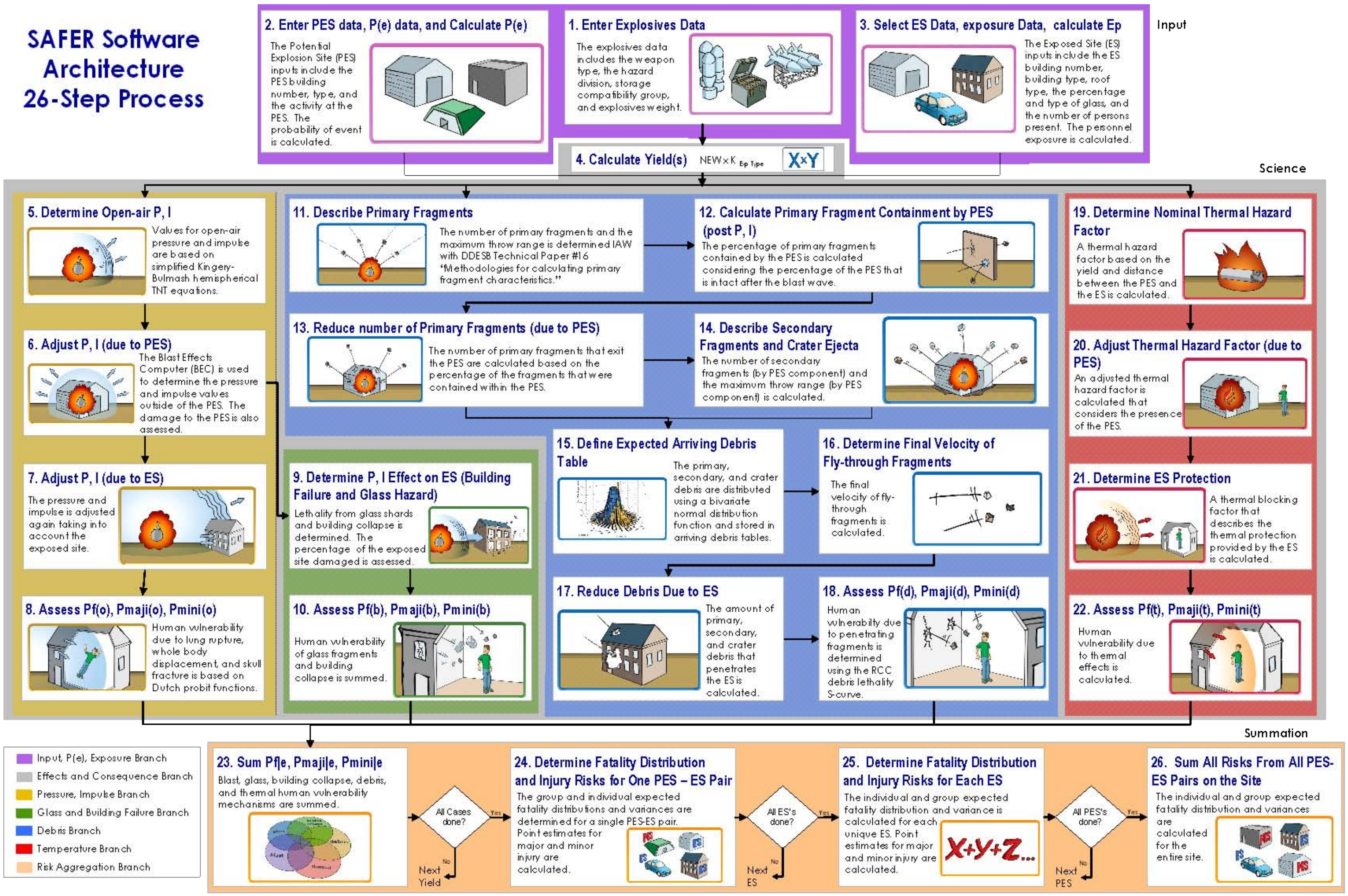

Figure 1. SAFER Architecture

3.1 Group 1 Steps: Situation Definition, Event and Exposure Analysis

The Group 1 steps are where all of the input values are defined for the risk analysis. In SAFER, these steps are populated via the user interface, whereas the calculations performed in the rest of the steps are all done "behind the scenes," and are not presented to the user until the completion of the Group 6 steps provides the various outputs. The four steps that comprise Group 1 are as follows:

- Step 1: Enter explosives data
- Step 2: Enter PES data, probability of event (P_e) data, and compute P_e
- Step 3: Enter ES data, exposure data, and calculate exposure
- Step 4: Calculate yields

The various parts of these steps that have been identified as needing to be updated are discussed below.

Step 1: The most pressing aspect of Step 1 that needs to be updated is related to the weapon types that can be selected. The existing weapon types in TP 14 will be updated, and additional weapon types will be added. The existing weapon types for each Hazard Division (HD) were chosen to be a fairly conservative representation of weapon types in the HD. At a minimum, weapon types will be added that provide a better general representation of the fragmentation hazard for a given HD. The weapon characteristics will be derived from the TP 16 database, and it still remains to be seen if all weapons in the database will be included, or if a handful of common, representative, and worst-case weapons based off of the group's opinion are added. Whichever path is chosen, it was also deemed desirable to allow an option for a user-defined weapon type.

The Science Panel is also looking into the feasibility of basing orientation/stack geometry on weapon type, activity type, and/or facility type (storage, manufacturing, etc.). SAFER currently assumes a default stack geometry for all weapon types. Given that there are certain weapon, storage, and activity type combinations where the orientation and stack configurations of the munitions are known, it would be advantageous to use this information as the default stack configuration. Additionally, a user-defined stack configuration could also be implemented to allow the user more freedom to define the risk scenario. Of course, it should be kept in mind that when siting, the vast majority of the time the user only sites for an HD amount, as the weapon type stored will vary over time.

The option of expanding the types of HD 1.3 in the weapon list has been discussed, with the additional prospect of considering HD 1.3 in confinement. It was decided that it would be a good idea to wait and see where the QD criterion for HD 1.3 in DoD 6055.09-STD is headed prior to making changes in TP 14. Additional options considered for Step 1 include the option of adding energetic liquids when selecting a hazard type, and considering height of burst, mixing HDs implicitly within the software, or defining the location of the NEW within the PES itself. Ultimately these issues were deemed either low priority or not feasible at this point.

Step 2: The group identified two PES categories that it would like to immediately add to Step 2: a Truck and an ATF Magazine. There are multiple sizes and types of both, so the next step is to decide how many of each type should be included in TP 14. Both of these PES types already exist within IMESAFR[7], so the effort to incorporate them into SAFER shouldn't be too extensive.

The argument for including a user-defined PES is compelling, though it remains to be seen if this will entail allowing for a user-defined PES from scratch, or if scaling an existing structure is adequate (or perhaps changing the footprint ratio, i.e. square vs. rectangle). Additionally, there is a need to allow the user to define the presence of a barricade at the PES in future versions of the software. Due to the complexity of the problem, the software could not initially verify whether or not the barricade would block the debris or even become part of the secondary debris generated; this information would have to be verified offline.

Step 3: The future changes for Step 3 are very similar to those decided for Step 2, namely to add additional ES types in TP 14. The ultimate goal is to have a user defined ES types which would allow for component based damage and fatality algorithms. User-defined ES types could be developed much easier than user-defined PES types, which have to consider detailed properties of the secondary debris generated in all directions.

It was also determined that additional window layup types and sizes are needed, as the existing choices are very limited. The window response and resulting hazard are largely dependent upon the size and layup type, so allowing additional user input would provide higher fidelity in the final risk answer.

Finally, it was also decided that the protection from overpressure that a barricade at the ES provides should be considered. Similar to definition of a barricade at the PES in Step 2, the software would not perform the structural calculations to determine if the barricade retains its structural integrity and does not hazard the occupant of the building, as that would need to be calculated off line.

Step 4: This step is a fairly simple one, yet causes some confusion to users. The confusion stems around the "Expected NEW" and the "Expected Yield" in Table 7 of TP 14, particularly that the Expected Yield wasn't the yield that would occur from the Expected NEW. SAFER is actually calculating four different yields in this step from the "Sited NEW," the "Expected NEW," the "Maximum Yield," and the "Expected Yield." The Expected Yield values from Table 7 are based on test and accident data, as very rarely does the entire amount of explosives contribute to the event, even for mass detonating items. From a risk-based siting standpoint, only the value generated from the Sited NEW and Maximum Yield is used, as siting takes a worst-case approach to the yield of the event. The other values are more appropriate for operational risk management, where there is no strict criterion that must be met, and to try to reduce risk at those locations with current site approvals. It was thought that if SAFER had two different tabs, a Risk Siting Tab and a Risk Management Tab, then some of this confusion could be eliminated.

3.2 Group 2 Steps: Pressure and Impulse Branch

The steps in this group determine the overpressure and impulse that reach personnel at each ES, and quantify the associated probabilities of injury and fatality due to the various mechanisms associated with the blast wave. The steps of Group 2 are as follows:

- Step 5: Determine open-air Pressure, Impulse (P, I)
- Step 6: Adjust P, I due to PES
- Step 7: Adjust P, I due to ES
- Step 8: Assess probability of fatality and injury due to overpressure

Steps 5 and 6 calculate the pressure and impulse at a given distance due to factors such as TNT equivalency, equivalent load based on weapon type, and attenuation provided by the PES structure. Step 7 adjusts the pressure and impulse at the location due to the presence of the ES. The amount of this reduction is largely dependent upon the amount of windows present in the ES. Step 8 calculates the consequences on human injury and fatality due to lung rupture, whole body displacement, and skull fracture. At the end of Step 8 all of these fatality mechanisms are aggregated for a final consequence answer due to overpressure and impulse. The issues with the existing algorithms for these steps and proposed paths forward are identified below.

Step 5: The most significant issue with the current algorithms of Step 5 (as well as Step 6) is that the pressure and impulse equations are not identical to the latest version of Blast Effects Computer (BEC)[8]. The current equations are from a previous version of BEC, and have not been updated to those in Version 6. BEC Version 6 uses independent NEW arguments for the pressure and impulse calculations, whereas TP 14 uses the same NEW argument for pressure and impulse – the way BEC calculated pressure and impulse in previous versions. This effect is minor or negligible for the vast majority of cases, but certain scenarios that have a high degree of directionality in the blast loads show a non-negligible difference.

Another potential change for Step 5 is to allow the user to change explosives type for a particular weapon type. Currently, TP 14 assumes an explosive fill for a given weapon type, but there are scenarios where a given weapon type can have multiple configurations that have different explosive fills. This is consistent with the philosophy of keeping default values, but at the same time allowing for increased input into the risk calculation for higher fidelity in the final risk answer. The effect that this would have on the BEC output values on pressure and impulse would need to be quantified prior to implementation.

Step 6: Step 6a calculates the pressure and impulse values outside the PES, particularly the attenuation of the blast wave provided by the PES structure. Similar to the comments above regarding future changes to Step 5, the equations here should be consistent with the latest version of BEC.

Step 6b deals with calculating the amount of the PES that is still intact as a function of the NEW. The parameters involved in this calculation (the Y_0, Y_{100}, a, and b values of Equation 30 and Tables A-6 to A-9) were based off test data, analysis, and engineering judgment, but will be reexamined using the latest test data and analysis methods. The aforementioned concept of a user-defined PES in Step 2 has the first of many issues arise in this step. There would need to be some gross assumptions made for the user-defined PES to create the parameters in this step, and they would undoubtedly need to be fairly conservative due to the uncertainty involved.

Step 7: The equations in Step 7 that calculate the overpressure and blast wave characteristics that leak into a structure were based on UFC 3-340-02[9] and other similar methodologies. Despite this, they are in need of updating as they were created considering a specific valid range of NEW that has now been exceeded. This is the first example of methodologies and algorithms created for a certain range of applicability that has now been superseded by updated user requirements. New equations with a similar intent will be created for SAFER 3.X, and it's possible that a major philosophical change could be made for versions of SAFER further down the road.

Step 8: This step assesses probabilities of fatality, major injury and minor injury due to pressure and impulse effects – lung rupture, whole body displacement, and skull fracture. The algorithms in this step have been compared with other models in the international risk analysis community and have been in good agreement. While there are no major contentions for any particular algorithm in this step, the general consensus of the group is that the methods within AASTP-4[10] should be assessed, and the goal of TP 14 should be to have consistency with the accepted state-of-the-art in this area.

3.3 Group 3 Steps: Structural Response Branch

These steps analyze human vulnerability from building collapse and glass hazards. The steps of Group 3 are as follows:

- Step 9: Determine adjusted P, I effect on ES (building and glass hazard)
- Step 10: Assess probability of fatality and injury from building collapse and glass hazards

The bulk of the analysis occurs in Step 9, while Step 10 simply aggregates the consequences. The largest challenge moving forward for the Group 3 steps is implementation of a user-defined ES, particularly the effect that it would have on the algorithms of Step 9.

Step 9: The first part of this step, Step 9a, assesses the hazard to persons due to window breakage. When new window types/sizes are included and the existing types are re-examined using the current state-of-the-art, all of the algorithms in this step will change.

New consequence algorithms that quantify probability of fatality as a function of pressure and impulse will be developed for a number of window types and sizes.

Steps 9b and 9c deal with fatalities due to building collapse and building damage. The group envisions moving to an ES component-based response approach, which would change all of the equations in these sub-steps. An intermediate step for SAFER 3.X before going to component-based algorithms could include items such as developing wall damage algorithms instead of using the total building damage ones, or having a step-based fatality approach where the loss of a wall will result in increased fatalities.

If the composite damage approach is maintained for SAFER 3.X, the group shall enhance the current Simplified Close-In Fatality Mechanisms (SCIFM) algorithms. In addition to addressing the SCIFM algorithms, SAFER 3.X shall include warning flags for the few scenarios where an unconservative answer could arise due to the range of use for the program expanding since the inception of SAFER 1. These flags will have simple criteria that must be satisfied to make sure that the answer is acceptable.

Step 10: The basic equations of this step are satisfactory, but they could be enhanced. The first issue is that polytrauma is not considered (this applies to Step 8 also). If an individual receives major injury from glass and major injury from building collapse, at what point should that result in a fatality? Polytrauma is a very difficult problem, but should at the very least be addressed in the future. Perhaps the first step is to reexamine the past efforts sponsored by the RBESCT to advance injury and fatality prediction algorithms.

A second issue is that the glass and building collapse hazards both use SCIFM. One goal of TP 14 is to ultimately do away with SCIFM by developing standard algorithms that are adequate for any scenario.

3.4 Group 4 Steps: Debris Branch

The most complex portion of the consequence equations for the physical hazards associated with an accidental explosion is the Debris Branch. The steps of Group 4 are as follows:

- Step 11: Describe primary fragments
- Step 12: Calculate primary fragment containment by PES (post P, I)
- Step 13: Reduce number of primary fragments (due to PES)
- Step 14: Describe secondary fragments and crater ejecta
- Step 15: Define expected arriving debris tables
- Step 16: Determine final velocity of fly-through fragments
- Step 17: Reduce debris due to ES
- Step 18: Assess probability of fatality and injury from debris

Step 11 determines the number of primary fragments that are expelled from a stack and the associated maximum throw distance as a function of mass. Step 12 calculates the number of primary fragments that are contained by the PES, while Step 13 removes these fragments from the debris tables generated. Step 14 defines the fragments generated from both the PES itself and the crater. Step 15 sums the all of the primary, secondary, and crater debris and defines the expected debris arriving at the ES, along with the trajectory category of the impacting fragments. Step 16 calculates the velocity of the low angle fragments striking the wall of the ES. Step 17 accounts for the debris protection afforded to the occupants of the ES, while Step 18 determines the human vulnerability from debris and aggregates the probabilities of fatality.

One general note about the Group 4 Steps is the way steel fragments traveling at terminal velocity are handled. For reinforced concrete debris, there are currently no modifications that need to occur when transitioning from Mass Bins to Kinetic Energy (KE) Bins. For example, a piece of concrete debris in Mass Bin 8 falling at terminal velocity has a kinetic energy that resides in KE Bin 8. This is not true for steel fragments, as a "bin shifting occurs" for steel fragments falling at terminal velocity. A piece of steel debris in Mass Bin 8 falling at terminal velocity has a kinetic energy that resides in KE Bin 7, and hence all steel debris at terminal velocity in Mass Bin 8 is shifted to KE Bin 7. As later versions of SAFER were developed, more detailed information became available on the actual mass and velocity of each piece, which in turn would allow SAFER to characterize the actual KE more accurately. However, the bin shifting methodology is still in place in the current version of SAFER, and this logic will be revised for SAFER 3.X. This affects all aspects of debris, so the steel mass distributions for secondary debris will have to be recalculated at the same time. This issue occurs throughout all of the Group 4 Steps, and will not be addressed in detail in any individual step.

Step 11: Many of the weapons' characteristics will be recalculated when the weapon types are investigated and made consistent with the current TP 16 database. Particularly, Tables 14 and 15 would need to be repopulated with new or updated values depending on which munitions are included.

As touched on in the Step 1 discussion, the determination of the number of primary fragments exiting from a stack within the PES assumes a certain stack geometry, which may or may not be correct. A stack geometry must be assumed based on the NEW and number of weapons, and unfortunately a default geometry has its limitations. It would be possible to tie the aspect ratio of the stack to that of individual items that are in the database, but that could introduce a new set of issues.

Finally, a valuable feature in the tool would be to allow the user to "turn-off" primary fragments. Currently, even Bulk/light case has some number of primary fragments assigned to it, and it would be greatly beneficial to turn it off to isolate the effects of primary fragments.

Step 12: The first issue to be addressed in Step 12 is the breakdown between High Angle, Fly-Through, and Side-Impact fragments. This needs to be reinvestigated, and the

resulting output would come out of a TP 16 type investigation in conjunction with a trajectory code performing the analysis. It would need to be determined, as a function of distance, how many fragments fall into each of the three aforementioned categories. This would be a fundamental change with how the primary fragment velocity algorithms are handled.

Another issue is Step 12 to be addressed is the initial velocity of primary fragments that detonate inside a PES. The Science Panel deemed that it is appropriate to limit the velocity of the primary fragments to that of the secondary fragments for robust building types. Currently, TP 14 treats primary fragments as if they were unaffected by the presence of the PES for loading densities that completely destroy the PES, which is conservative. It would still be necessary to account for some fragments that escape unimpeded from robust buildings using the fragment blocking coefficient, but conversely, a weak buildings would still be able to "hold onto" fragments and reduce their velocity to that of secondary debris. For example, a reinforced concrete structure may have a blocking factor of 0.90, while a pre-engineered metal building may only have a blocking factor of 0.10.

Step 13: This step reduces the fragment blocking ability of the PES due to the damage caused by the NEW and removes the "blocked" fragments from the departing primary fragment tables. As alluded to in Step 12, the Science Panel felt that this conservatism should be reconsidered, and that the fragment blocking coefficients should be updated to reflect this new methodology.

Step 14: This step defines the secondary fragments and crater ejecta generated. Steps 14a and 14b relate to the secondary fragments while Steps 14c and 14d pertain to the crater ejecta generated by an event.

The most significant issue with Step 14a relates to the dynamic mass distribution. It is acknowledged that, according to available test data, the dynamic mass distribution is not nearly as proactive as it should be. The mass distribution of a component defines how many pieces of what size are generated for a given NEW. Looking at the extreme cases, for a given PES structure a very small NEW will break a wall into a single piece as it fractures at the supports. For that same PES with an unreasonably large NEW, the wall will break into hundreds of thousands of pieces, with the largest piece being no bigger than the size of the aggregate in the concrete. This is an extreme example, but it illustrates the dependency of the mass distribution on the NEW. The current dynamic mass distribution, the function that alters the baseline mass distributions according to the NEW in the donor, does not "convert" larger pieces into smaller pieces as aggressively as it should. This was originally done intentionally, as the scenario was purposefully avoided where all of the "hazardous fragments" are converted to pieces so small that they are no longer hazardous at distance. Given that a large amount of test data exists for moderate NEWs and loading densities, the group decided to baseline the mass distribution around the test data, and allow it to move either up or down. The decision was made to also re-evaluate the actual mass distributions themselves, as this would need

to be done when the bin shifting issue is resolved anyway, and it would be beneficial to reassess the percent by bin and material for each PES type.

Step 14b calculates the maximum debris throw for the secondary debris. It was decided to compare the velocity and maximum throw distances with test data and adjust accordingly. Additionally, the spread of the debris distribution is based on the maximum throw distance, therefore it would be advantageous to plot that distribution and compare to test data, in addition to the maximum debris throw values.

Steps 14c and 14d calculate the debris hazard generated by the crater. There were no major issues addressed with the logic in the crater ejecta portion, but it would be a good idea to add new data to the curves and perform a comparison. One issue raised was that for debris flight considerations, SAFER assumes the soil has a density of concrete. The group entertained the idea of adding average masses for soil, but a version for inclusion of this enhancement was not identified.

Step 15: The basic breakdown of the fragments (High Angle vs. Side-Impact vs. Fly-Through for primary fragments and Side-Impact vs. Fly-Through for PES wall components) needs to be re-visited. It is an oversimplification to have a set fraction of this relationship, as it should be dependent upon PES type, loading density and distance. Additionally, SAFER can eventually advance to a cloverleaf debris pattern to predict debris density as a function of azimuth, but that will require the use of a GIS interface and would not happen until integration of the risk-based siting tool with ESS.

Table 24, the table with the reduced debris throw factors, can definitely be improved in the meantime. The current approach for debris throw with respect to orientation [for hardened aircraft shelter (HAS) and earth-covered magazine (ECM) PES types] has limitations that need to be addressed.

Step 16: The equation to calculate final velocities needs to be reexamined and the initial velocities for both primary and secondary debris need to be studied to ensure realistic values are in place. The equation yields accurate results for its intended purpose, but the pieces of the equation taken out of context will not produce realistic predictions.

Another philosophical decision to be made at this step is the manner in which the Fly-Through fragments are treated in the calculations. If the final velocity for Fly-Through fragments in a given Mass Bin is calculated at less than terminal velocity for that particular Mass Bin, the velocity of the fragments is artificially set to terminal velocity for that Mass Bin. This was a decision made in the past to maintain the conservatism of the answer, but will be revisited.

Step 17: The Science Panel felt that the basic concept of Step 17 was sound, but the perforation thresholds could be constantly updated as the results of new test data are gathered. One proposed update to the methodology itself is to define KE threshold perforation values as a function of material type. Recent test series[11, 12] have provided

threshold perforation information as a function of impactor type for both steel and concrete. Additionally, the long-term goal of Step 17 is to define perforation thresholds for the various wall and roof components as a function of mass and velocity, rather than just kinetic energy.

One issue relates to the validity of assuming that the roof/walls fail prior to the debris getting there. For example, a wall that takes a long time to respond in flexure may still be present when the debris arrives. This could add some unnecessary conservatism in certain areas, but was deemed a low priority and a relatively minor issue.

Step 18: This step calculates the probability of lethality, major injury, and minor injury due to debris impacts. This is a function of the fragment description, the vulnerable area of an exposed human, the consequences given a fragment hit, and the probability of a hit. There are no major issues identified with respect to the effects aggregation, but the application of a Poisson distribution needs to be scrutinized.

The relationship between debris impact energy and probability of fatality was originally based on the relationship provided in RCC Standard 321-00[13]. That relationship in the RCC Standard has slightly changed in the latest revision, and the effect on the probabilities of fatality per Mass Bin given a debris hit should be fully investigated.

3.5 Group 5 Steps: Thermal Branch

SAFER only considers thermal effects and consequences if the situation includes a HD 1.3 event. In this case, SAFER does not consider the other consequences mechanisms due to the lack of a blast wave being formed. The steps of Group 5 are as follows:

- Step 19: Determine nominal thermal hazard factor
- Step 20: Adjust thermal hazard factor (due to PES)
- Step 21: Determine ES protection
- Step 22: Assess probability of fatality and injury from thermal hazards

The Group 5 Steps very nearly mimic the Group 2 Steps of the Pressure and Impulse Branch. Step 19 determines the nominal thermal hazard independent of the PES. Step 20 adjusts the thermal hazard due to the presence of the PES. Step 21 determines the thermal protection provided by the ES, while Step 22 calculates the consequences due to the thermal hazards.

Step 19: For the time being, using the cube root of the NEW in Step 19 is satisfactory for assessing thermal hazards. The DDESB is currently in the process of investigating the feasibility of updating QD criteria for HD 1.3 such that it better represents the true hazard associated with a deflagration event, to include the effects of HD 1.3 in confinement. It is anticipated that the criteria will no longer be totally NEW dependant; TP 14 shall change accordingly when QD criteria does.

Step 20: The Science Panel decided that the thermal reduction assumptions due to the presence of the PES should be reconsidered. It was also suggested to consider overpressure when HD 1.3 is provided confinement, but may be better addressed with words in either TP 14 and/or TP 19. This issue may also be superseded by any changes in DoD criteria as it relates to HD 1.3 effects.

Step 21: As with the previous step, the thermal protection that the various ES types provide should be re-examined, as well as how the presence of windows are treated in the calculation.

Step 22: The current algorithms of TP 14 essentially define the probability of fatality as approximately zero outside the fireball radius, and being equal to one inside it. The algorithms should be updated with the current state-of-the-art in this area, and changed accordingly.

Additionally, SAFER currently does not include thermal effects for all other HD cases, as it is "turned off" for other HDs. It is important to calculate thermal hazards for some scenarios, and would be an easy implementation; the Thermal Branch would just need to be turned on to address this issue.

4.0 INTEGRATION WITH ESS SOFTWARE

Many of the aforementioned improvements in TP 14 would be greatly aided by incorporation into an interface that provides geospatial data. It is the goal of the DDESB to have its risk-based explosives siting tool integrated with the ESS software tool by October 2013. This will provide multiple benefits to the users of the tool, as well as the entire explosives siting process. From the user's standpoint, this will significantly reduce the amount of information needed to perform a risk analysis, as well as remove some of the risks associated with erroneous input values. From the standpoint of algorithm development in TP 14, the automation of these geospatial relationships provides the opportunity to increase the accuracy of the prediction models. A general overview of these implications is discussed below.

A common confusion in setting up a risk analysis is which facilities must be included when calculating the Group Risk of a scenario. The methodology operates under the basic assumption that risk-based siting is being used because QD is not satisfied between a PES/ES pair. With this assumption in mind, the "group" for which the Group Risk criteria apply to, is comprised of all the ESs that have a non-negligible individual risk from the PES in the PES/ES pair that violates QD; further, the non-negligible individual risk presented to these ESs from any other surrounding PESs must also be considered. The preceding description is quite brief, and a more detailed definition and procedure can be found in TP 19. However, this problem is alleviated with integration of geospatial

data. The PES siting tree for calculation of Group Risk is automatically generated, preventing the need to determine which PES and ES facilities must be included.

The methodology operates under the basic assumption that risk-based siting is being used because QD is not satisfied between a PES/ES pair. With this assumption in mind, the “group” for which the Group Risk criteria apply to, is comprised of all the ESs that have a non-negligible individual risk from the PES in the PES/ES pair that violates QD; further, the non-negligible individual risk presented to these ESs from any other surrounding PESs must also be considered

The spatial relationships defined in the GIS databases will also be used to populate the orientations and distances between PESs and ESs. This will eliminate the need for the user to determine the distances between facilities, as well as providing input as to their orientation. Currently, TP 14 only considers orientation by sector for earth covered magazines and hardened aircraft shelters in accordance with DoD 6055.09-STD.

Another advantage of integrating with ESS is that some of the facility information is already input into software for QD siting that is also used for risk-based siting. In particular, the explosives information for PES facilities is already defined, removing the need for the collection/entering of that information twice. Furthermore, a limited amount of facility information may be extracted from the GIS database and used to populate the input parameters.

In addition to the aforementioned advantages for the user upon integration with ESS, there are quite a few advantages from the standpoint of algorithm development. It has been the desire of the Science Panel for many years to incorporate algorithms into the risk-based siting software that account for the cloverleaf debris pattern that occurs for rectangular donor structures. The debris density at an ES from a given PES then becomes a function of both the distance and the orientation of the ES with respect to the PES, or more specifically the azimuth off the normal of the PES. This information is highly impractical to include in the current version of the software, but would require little to no additional input from the user to account for this effect upon availability of geospatial data.

Similar to enhancing the debris density predictions by utilizing the geospatial relationships and orientations stored in the GIS database, the building damage algorithms and associated fatality prediction can be greatly enhanced by utilizing existing data. The current default algorithms in TP 14 for building damage from the blast wave are independent of building orientation. They were developed as an average damage independent of charge location, and are a function of the incident pressure and impulse. If the orientation of the building is known, the angle of incidence on each reflecting surface can be calculated, and a better approximation of building damage and fatality can be generated. Additionally, inclusion of the aspect ratio and relative dimensions of the building will also improve the fidelity of this calculation.

5.0 CONCLUSION

The development of risk-based siting remains an evolutionary process, as science is constantly improving prediction algorithms for the complex events associated with explosives scenarios, gradually improving accuracy and asymptotically approaching the best point estimate of the "answer." It is the responsibility of the RBESCT to implement and oversee risk-based siting in the DoD, and it is the function of the DDESB Science Panel to develop and improve the explosion effects and consequence algorithms detailed in DDESB TP 14.

The various algorithms of and proposed updates to TP 14 have been presented, and the relative philosophy moving forward has been discussed. Algorithm development is being conducted with both the user requirements and the ultimate purpose of this tool in mind.

Integration with ESS will be greatly beneficial for both the users of the software and for the development of the consequence algorithms of TP 14. From a user standpoint, integration with geospatial data will automatically generate much of the input needed for a risk analysis. In addition, the geospatial data and orientation information provided within the GIS databases will allow for more accurate prediction algorithms to be developed.

Whether used for explosives siting purposes or for operational risk management, risk-based analysis methods provide a state of the art assessment technique for explosives safety. The ultimate goal of the DDESB is to enhance explosives safety, and constantly improving the prediction algorithms of TP 14 does just that.

6.0 REFERENCES

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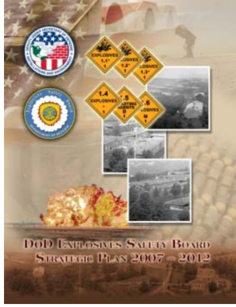

The Future of SAFER Science and Integration of DDESB's Risk-Based Explosives Siting Tool with ESS

Robert T. Conway
Naval Facilities Engineering Service Center

John W. Tatom
APT Research, Inc.

Lea Ann Cotton
DoD Explosives Safety Board

Phillip C. Wager
Naval Facilities Engineering Service Center

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- Overview of Update
- Situation Definition, Event and Exposure Analyses
- Pressure and Impulse Branch
- Structural Response Branch
- Debris Branch
- Thermal Branch
- Integration with ESS Software
- Conclusions

Background

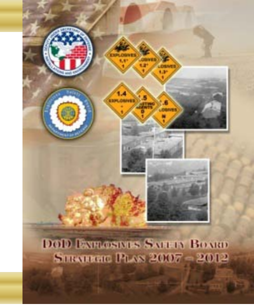
- SAFER 1.0 was originally released in May 2000
- Technical Paper (TP) No. 14 details the DDESB approved methodology for risk-based explosives siting
- Current version, SAFER 3.1, was released in 2009
- The constant goals of the revisions are to:
  - Enhance the capabilities of the software
  - Expand the range of validity
  - Improve consequence models and maintain consistency with the scientific state-of-the-art
- The DDESB Science Panel is in the process of revisiting all algorithms and methodologies currently in TP 14

Overview of Update

- The rationale behind any suggested change in TP 14 is for one of the following reasons:
  - The state-of-the-art for a particular consequence algorithm has improved since the initial implementation
  - The use of SAFER has expanded beyond the original range of applicability for a given consequence algorithm
  - Incorporation of geospatial relationship data (through integration with ESS) would facilitate improvement or fidelity of some algorithms without requiring additional user input
- The Science Panel is taking both a short-term and long-term approach for suggested improvements. Updates will be targeted for the next stand-alone version of the software (SAFER 3.X), whereas other changes will be identified for implementation when the DDESB's risk-based explosives siting tool is incorporated with ESS

Philosophical Overview

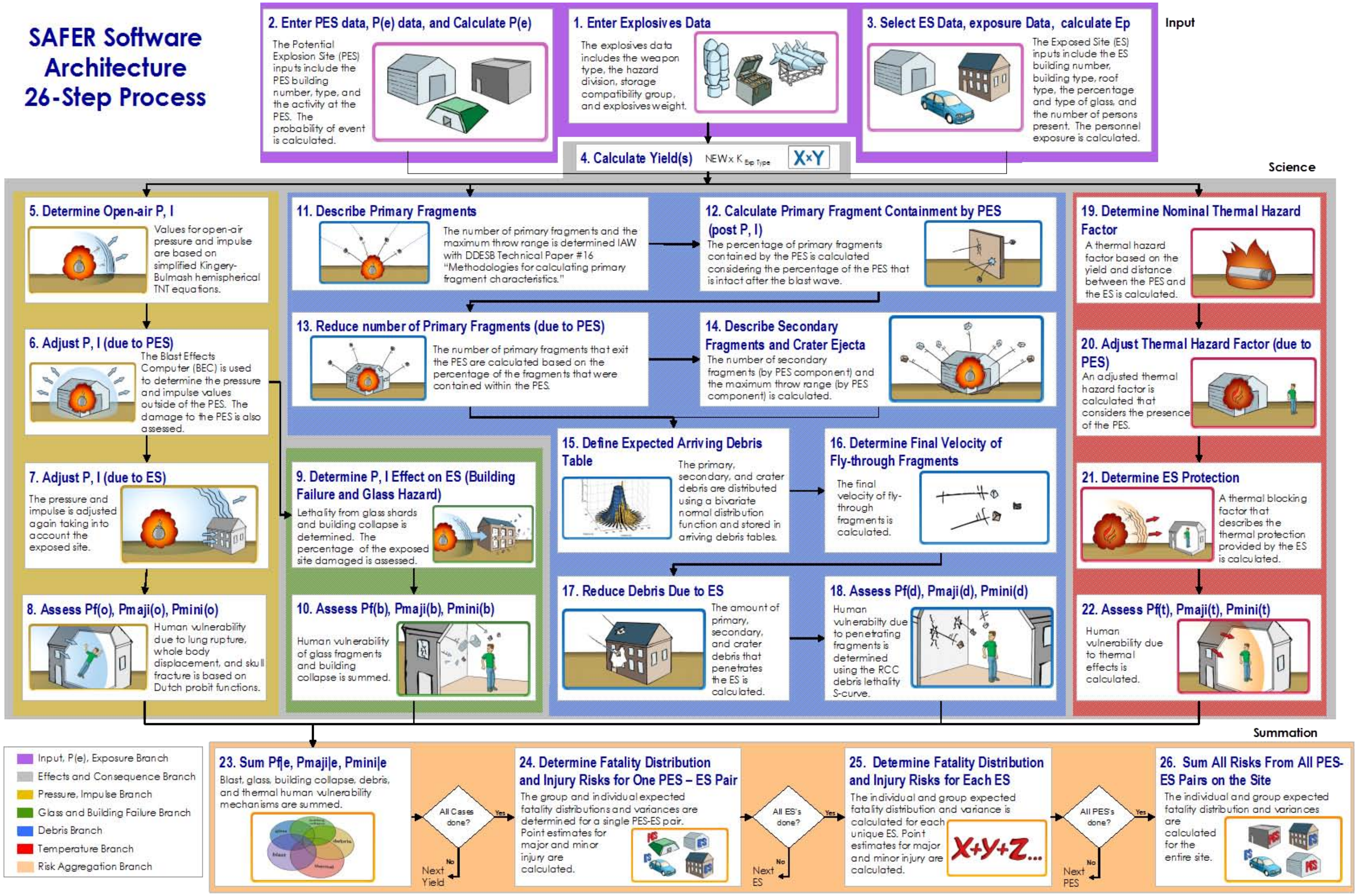
- Science constantly improves over time and asymptotically approaches the best point estimate of the “answer”
- User requirements and the range of desired use are dynamic by nature and continually evolve over time
- What is the purpose of this tool?
  - An explosives safety siting tool/alternative to Quantity Distance (QD) siting?
  - A state-of-the-art engineering analysis tool?
- What is the goal of risk-based analysis?
  - To do a better job of risk management than QD siting?
  - To create a hybrid analysis tool that performs engineering analyses, risk-based siting, and operational risk management?
- All of these aforementioned issues are being considered by the DDESB Science Panel as the algorithm update of TP 14 is being conducted



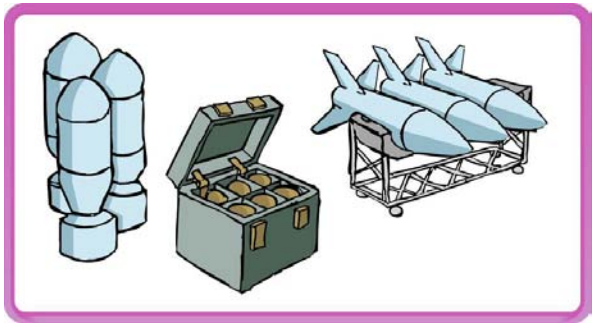
The six “Groups” and 26 “Steps” of TP 14

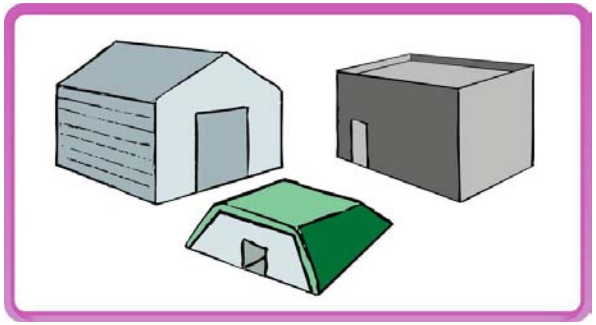
Group 1	Steps 1-4	**Situation Definition, Event and Exposure Analyses** Includes user inputs that describe the situation (PES and ES) and calculates P_e, exposure, and yield
Group 2	Steps 5-8	**Pressure and Impulse Branch** Calculates the magnitude of the fatality mechanisms of pressure and impulse
Group 3	Steps 9-10	**Structural Response Branch** Calculates the magnitude of the fatality mechanisms of building collapse and broken windows (overall building damage)
Group 4	Steps 11-18	**Debris Branch** Calculates the magnitude of the fatality mechanisms for multiple types of flying debris
Group 5	Steps 19-22	**Thermal Branch** Calculates the magnitude of the fatality mechanism of thermal effects for HD 1.3 scenarios only
Group 6	Steps 23-26	**Aggregation Summation** Aggregates the total magnitude and risks of all fatality mechanisms, calculates the desired measures of risk, and assesses overall uncertainty

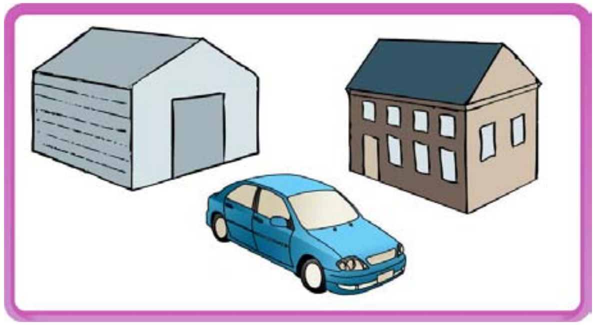
SAFER Architecture



Group 1 Steps: Situation Definition, Event and Exposure Analyses





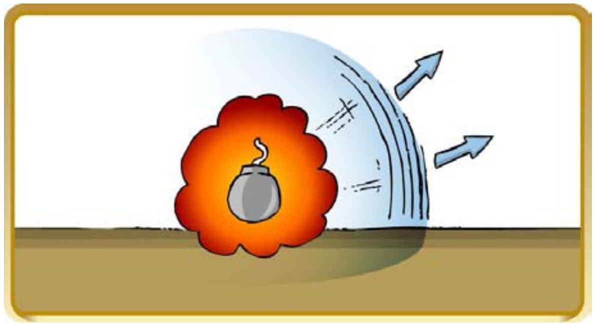


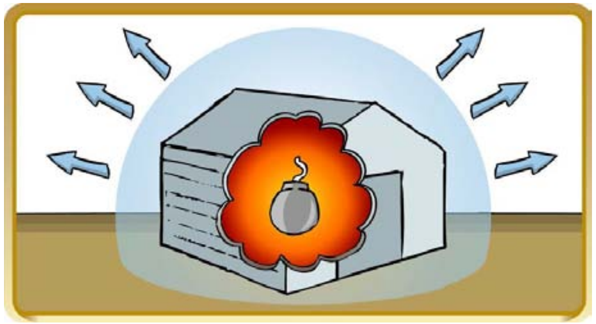
- The Group 1 Steps represent the portion of TP 14 that is “seen” by the user
- The explosives data is entered in Step 1
- The Potential Explosion Site (PES) data is entered in Step 2
- The Exposed Site (ES) data is entered in Step 3
- Exposure, probability of event, and explosive yields are calculated based on input from the user

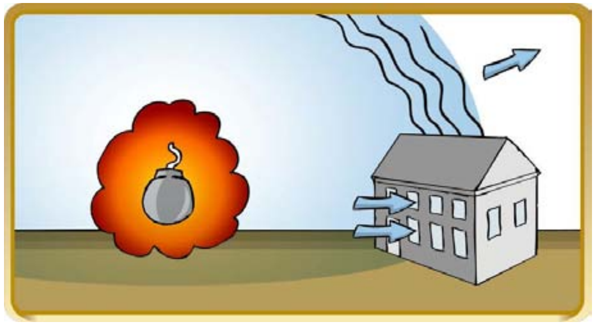
Updates to Group 1 Steps

- Add new weapon types and update existing weapon types
- Improvement on stack geometry, and potentially basing it on weapon type, activity type, and/or facility type
- Add new PES types (Truck and ATF Magazine)
- Add a user-defined PES type (scalable vs. from scratch)
- Enhanced barricade options at both the PES and ES
- Allow for user-defined ES types
- Additional window layup types and size

Group 2 Steps: Pressure and Impulse Branch





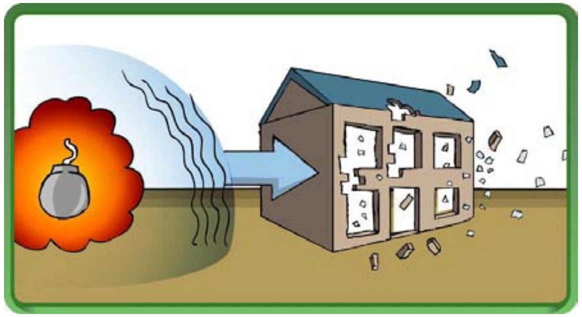


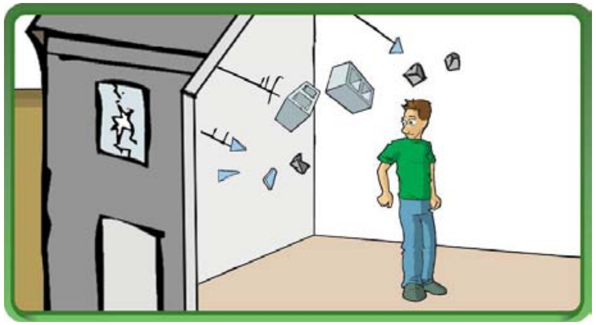
- Step 5 calculates the blast output (pressure and impulse) generated by the weapon
- Step 6 calculates the blast wave attenuation provided by the PES structure
- Step 7 calculates blast protection provided by the ES
- Step 8 assesses the probability of fatality and injury due to overpressure

Updates to Group 2 Steps

- Update pressure and impulse calculations to be consistent with latest version of Blast Effects Computer (Version 6.3)
  - Weapon types
  - PES types
- Consider allowing the user option to define the explosive fill in a weapon type
- Improve leakage pressure algorithms used to quantify the amount of overpressure that flows into structures
- Update the fatality algorithms with the latest state-of-the-art presented in NATO AASTP-4
  - Lung rupture
  - Whole body displacement
  - Skull fracture

Group 3 Steps: Structural Response Branch



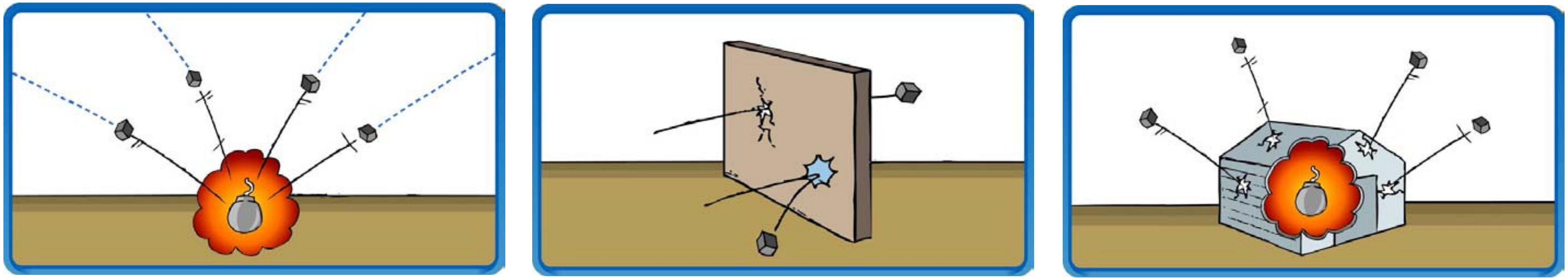


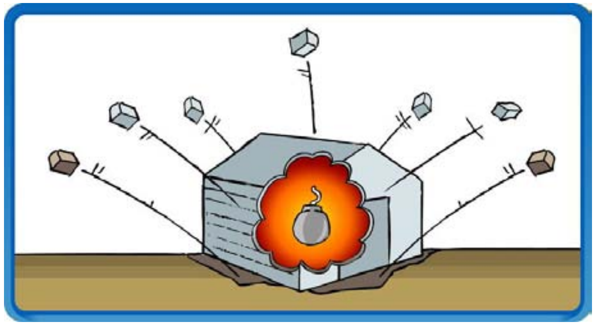
- Step 9a assesses the hazards to persons due to window breakage
- Steps 9b and 9c assess the hazards to persons due to building collapse
- Step 10 aggregates the probabilities of injury and fatality of this Group

Update to Group 3 Steps

- The addition of new window types and sizes will change all of the window damage and consequences algorithms in this step
- Component-based approach to building damage algorithms
  - Enables user-defined ES structures
  - Allows the use of the latest methodologies to define building damage
  - Physics-based debris throw models can be utilized to quantify probability of fatality due to blunt trauma impact
- Incorporation of warning flags for the existing models prior to updating to component-based response
- Investigate feasibility of considering polytrauma in the probability of fatality calculations

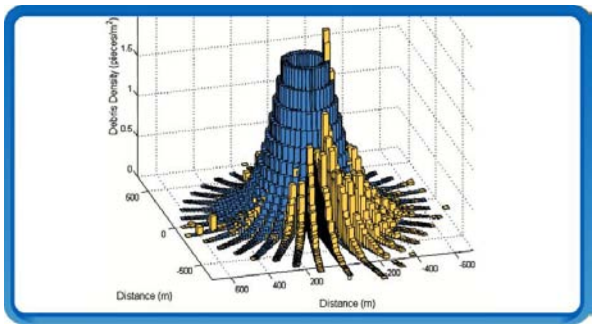
Group 4 Steps: Debris Branch

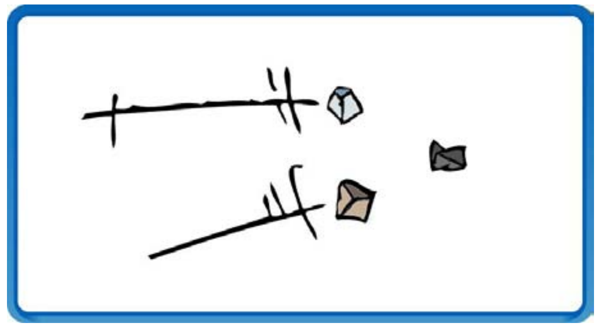


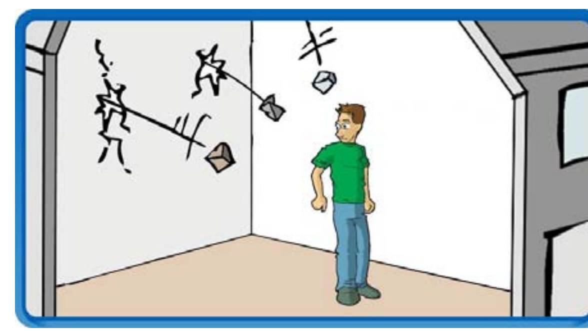


- Step 11 describes the primary fragments
- Step 12 calculates the primary fragment containment provided by the PES
- Step 13 reduces the number of primary fragments due to the PES
- Step 14 describes the secondary fragments and crater ejecta

Group 4 Steps: Debris Branch (continued)





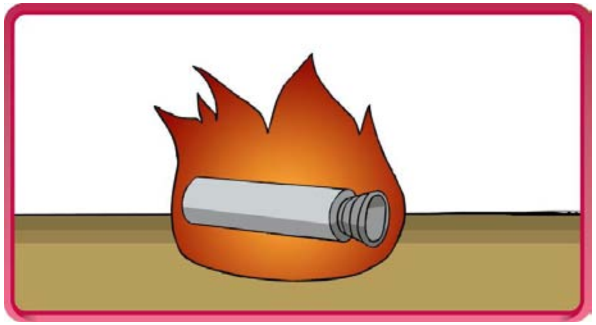


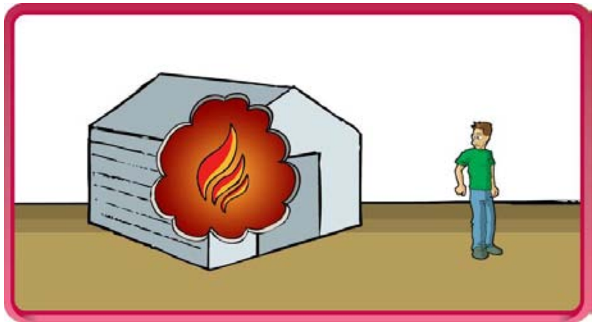
- Step 15 defines the expected arriving debris tables
- Step 16 determines the final velocity of fragments
- Step 17 reduces the debris due to the ES
- Step 18 assesses the probability of fatality and injury due to debris

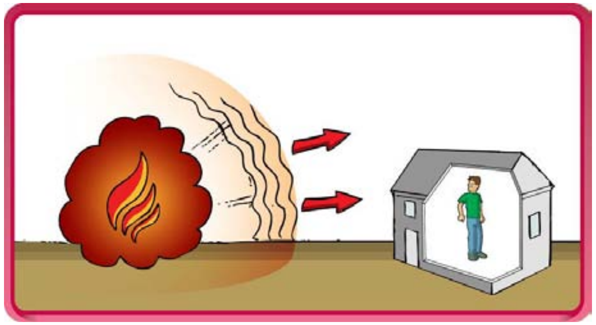
Update to Group 4 Steps

- Eliminate the current “bin-shifting” process for steel fragments at terminal velocity
- Make primary fragmentation characteristics consistent with the weapons in the most recent TP 16 database
- Reinvestigate High Angle vs. Low Angle (Side-Impact & Fly-Through) discretization of fragments
- Limit initial velocity of most primary fragments to that of secondary debris in a “heavy” PES
- Improve dynamic mass distribution
- Compare maximum debris throw and initial velocities to recent test data
- Remove conservative assumption of terminal velocity at impact
- Improve ES wall & roof perforation thresholds
- Consider timing of component failure and arrival of debris

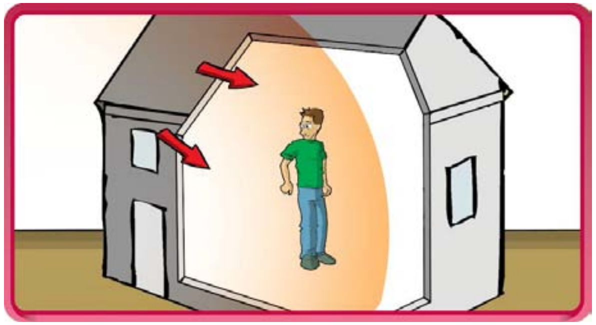
Group 5 Steps: Thermal Branch







- Step 19 determines the nominal thermal hazard
- Step 20 adjusts the thermal hazard due to the PES
- Step 21 quantifies the ES thermal protection provided
- Step 22 calculates the probability of fatality and injury from thermal hazards

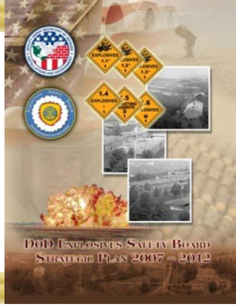


Update to Group 5 Steps

- Using the cube root of the NEW is satisfactory for the time being to assess the thermal hazard
- The QD criteria for HD 1.3 is currently in the process of being revised by the DDESB to better represent the true hazards from a deflagration event
- TP 14 shall change accordingly when DoD 6055.09-STD does
- The thermal reduction and protection at the PES and ES, respectively, need to be reconsidered
- The current thermal fatality algorithms, though consistent with other prediction methods, are fairly simplistic and should be updated with the latest state-of-the-art prediction methods
- The thermal branch is currently only used for HD 1.3 and should be activated for analyses of all other HDs

Integration with ESS Software

- Integration with geospatial data and GIS databases will greatly improve the DDESB's risk-based explosives siting tool
- From the user's perspective:
  - Distances and orientations are automatically generated
  - PES siting tree for Group Risk calculations is automated
  - Some facility information required for ESS (such as explosives information) removes the need to collect/enter the information twice
- From the perspective of algorithm development:
  - Ability to account for debris density as a function of azimuth (cloverleaf debris pattern)
  - Building damage can be calculated as a function of angle of incidence to the blast wave of each reflecting surface and the aspect ratio of the structure



Conclusions

- The development of risk-based algorithms remains an evolutionary process and is controlled by the scientific state-of-the-art, user requirements, and the overall purpose of the tool
- Various algorithms and proposed updates for the future of risk-based siting have been presented
- Integration with ESS will greatly benefit the users of the software and the development of consequence algorithms within TP 14
- Whether used for explosives siting purposes or for operational risk management, risk-based analysis methods provide a state of the art assessment technique for explosives safety. The ultimate goal of the DDESB is to enhance explosives safety, and constantly improving the prediction algorithms of TP 14 helps accomplish that goal